Appendix VII: Design & Evaluation Methods Crosscut

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DESIGN AND EVALUATION METHODS CROSSCUT

Validated design and evaluation methods are essential to the development of Generation IV systems that meet performance goals. Pre-conceptual design development is an integral part of the viability R&D to provide a focused set of objectives for technology development (e.g., for fuels and materials), to ensure integration and compatibility of system technologies, and to form the basis for more detailed design during subsequent phases of system development. System-specific design R&D activities are described in previous appendices. This appendix describes crosscutting design and evaluation methods R&D directed to (a) coordination of system design, analysis and evaluation activities across Generation IV systems, (b) development and qualification of crosscutting methods for design analysis of Generation IV systems, and (c) development of methodologies for evaluating overall system performance against Generation IV technology goals.

Design analysis of each Generation IV system requires a validated set of tools and databases to simulate neutronic, thermal hydraulic and mechanical/structural behavior in steady-state and transient conditions. For each system and type of analysis, the validity of existing analysis capabilities will need to be tested and the required enhancements to these capabilities implemented. Much of this development will be system-specific and is planned as part of the design and evaluation methods R&D for that particular system. There is a strong incentive, however, to coordinate the development activities across systems to avoid duplication of effort and to ensure that relevant developments in other national and international programs (e.g., the AFCI, NERI and I-NERI programs in the U.S.) are effectively utilized.

Beyond the coordination of analysis capabilities that are system specific, there are important opportunities to advance crosscutting analytical capabilities applicable to multiple Generation IV systems. Examples are Monte Carlo and deterministic transport methods for neutronics modeling, modern computational fluid dynamic (CFD) methods for heat transfer and fluid flow simulation, and modular code systems for fuel cycle evaluations and simulation of transients and postulated accidents. The opportunities for crosscutting advances in each area will help reduce uncertainties in predicted system behavior and ultimately contribute to improving system performance.

A need has also been identified in the Generation IV Roadmap to advance methodologies for evaluating overall system performance against the Generation IV goals of sustainability, economics, safety, reliability, proliferation resistance, and physical protection. Capabilities previously developed (e.g., the “Final Screening” methodology” developed by the Generation IV Roadmap Evaluation Methodology Group) require revision and extension to make them more quantitative, to improve their process for employing expert judgment, to quantify uncertainty in evaluated performance, to represent better unique features of Generation IV systems, and to account more comprehensively for important factors influencing performance. Application of these methodologies will help guide the R&D on the systems and provide a basis for judging the success of the R&D as it progresses, as well as for decisions relative to continuing the R&D direction for a particular system.

The crosscutting design and evaluation methods activities will be performed by a team of U.S. national laboratories, universities, and commercial organizations, in cooperation with GIF countries, and under the leadership of a national technical director. The national director is responsible to DOE for coordinating the effort and providing the required interface with Generation IV and AFCI national directors in other technical areas and with lead system design investigators in the Generation IV program and other programs.

Crosscutting design and evaluation methods R&D is divided into three major tasks: 1) coordination of system-specific design and evaluation activities, 2) development of crosscutting analysis methods for use in system design development and safety confirmation, and 3) development and application of methodologies for evaluating overall system performance against Generation IV goals. The activities, performing organizations, milestones, and budget allocations for FY 2003 and 2004 are given below. Finally, the description for each task is provided below for the seven-year period FY 2003 through FY 2009. Milestones for each year are subsequently specified.

1 COORDINATION OF DESIGN AND EVALUATION METHODS R&D

This task consists of two major activities. The first is to provide coordination of system design, analysis and evaluation activities across Generation IV systems, taking advantage of relevant advances in system design R&D in other national and international programs. The second major activity is to plan and oversee crosscutting design and evaluation R&D (described below). This activity has the objectives of advancing capabilities for system analysis, supporting system design optimization, and providing capabilities to assess system performance against Generation IV goals.

2 IMPROVEMENT OF DESIGN AND SAFETY ANALYSIS CAPABILITIES

The design of Generation IV systems will rely extensively on advanced simulation capabilities to provide accurate predictions of system performance. Viability of innovative system design features will require confirmation by credible analyses verified with experimental data. Also, credible analyses will be required as the basis for regulatory reviews and licensing of Generation IV designs of choice. Crosscutting activities directed to enhancing design and safety analysis capabilities are expected to include:

2.1 Computational Fluid Dynamics (CFD) Simulations

Although CFD has so far proven to be a useful design tool for light water reactor systems under normal operating conditions, its applicability for different types of coolants or for simulation of accident conditions remains to be established. To accomplish the Generation IV safety assurance objectives, creation of programs that increase the accuracy of CFD, extend its range of applicability, and experimentally validate its predictions as an engineering simulation tool will be important. The initial focus will be

on verifying the applicability of commonly-used CFD software for different types of coolants, distinct heat transfer regimes, and a wide range of flow phenomena.

2.2 System Dynamic Simulation Tools

A crosscutting systems dynamics tool for consistent assessment of concepts is needed. A planned activity is the evaluation, enhancement, and integration of modules from various system dynamics code versions that were previously developed for diverse reactor plant types. The proposed activity will advance such codes by integrating and validating existing capabilities, and extending them for analysis Generation IV systems.

2.3 Nuclear Data

The uncertainties in nuclear data for higher actinides are significant and they impact predictions of isotopic inventories, decay heat, and radiation emission characteristics. Data requiring additional assessments include energy release per fission, spontaneous fission model parameters, fission product yields, half-lives, decay energies, decay branching ratios, and radiotoxicity factors. Improved data need to be incorporated into inventory tracking tools to ensure that they give accurate results.

2.4 Monte Carlo Analysis Capabilities

The recent and continuing growth in computer power motivate the assessment and further development of Monte Carlo-based analysis capabilities applicable to multiple reactor types. Enhancement of these codes would also be investigated, including the propagation of errors as a function of depletion, provision of temperature interpolation capability, and modeling of thermal-hydraulic feedback.

2.5 Reactor Neutronic Design Codes

An integrated neutronic and depletion capability is needed for modeling non-equilibrium and equilibrium cycle operations of Generation IV systems, with representation of both their in-core and ex-core fuel cycle segments. Accurate modeling of systems with significant spectral gradients and changes of spectrum with depletion is a key requirement. The tool would employ advanced modules suitable for analysis of different Generation IV systems.

2.6 Sensitivity Analysis Capabilities

Uncertainties in reactor physics data lead to uncertainties in predictions of depletion-dependent system characteristics. By using sensitivity analysis methods, it is possible to avoid explicit recalculation of the effects for each data variation and at the same time to obtain information on additional data needs. This activity will develop an analytical tool for burnup dependent sensitivity evaluation and models for evaluating the uncertainties in predicted performance characteristics for different Generation IV designs.

3 DEVELOPMENT AND APPLICATION OF EVALUATION METHODOLOGIES

This task addresses the need for periodic evaluations of system performance against the Generation IV technology goals. Methodologies for conducting these evaluations will be developed by evaluation methodology working groups comprised of experts from national laboratories, universities, and industry. Because of the strong need to improve evaluation capabilities in the areas of economics and proliferation resistance and physical protection (PR&PP), the working groups for these areas were initiated in FY 2003. International experts sponsored by GIF countries participate in these working groups. Additional working groups may be formed to implement desired improvements in methodologies for evaluating system performance in the areas of sustainability, reliability, and safety.

An integrated nuclear energy economics model is central to standardized and credible economic evaluation of Generation IV nuclear energy systems. The innovative nuclear systems considered within Generation IV require new tools for their economic assessment, since their characteristics differ significantly from those of current Generation II & III nuclear power plants. In addition, the current economic models were not designed to compare nuclear energy systems featuring new fuel cycle and energy conversion technologies, or to evaluate economics of deployment in different countries or world regions. The *Economics Modeling Working Group* is charged with developing an integrated economics model applicable to the comprehensive evaluation of the economic performance of Generation IV nuclear energy systems.

Methodologies currently available for evaluating proliferation resistance and physical protection (PR&PP) of nuclear energy systems are limited by the lack of accepted figures of merit that provide a sufficient representation of system performance in these areas. A *PR&PP Methodology Working Group* has been formed to develop an improved methodology for assessing Generation IV systems. This group is charged with developing a systematic method for evaluating and comparing the proliferation resistance and physical protection of these systems, including their fuel cycle facilities and operations. To the maximum extent possible, a quantitative and standardized methodology is targeted, as is the ability to identify system features that contribute to the overall resulting assessment of the comparative PR&PP of the system.

The evaluation methodology working groups will focus primarily on developing, testing and verifying the required methodologies, but are also expected to contribute to the application of the methodologies to Generation IV systems. Because the comprehensive evaluation of a Generation IV system using the methodologies is a significant undertaking likely requiring additional expertise to that of working group members (e.g., detailed familiarity with system design), a dedicated effort will be needed to perform these evaluations when required. Contributors to this effort are expected to include methodology working group members and other experts providing the additional expertise needed. Results of the application studies will be used for periodic re-assessment of system potential and for guiding R&D priorities.

4 DESCRIPTION OF FY 2004 SCOPE

Fiscal year 2004 scope is divided into three major areas: coordination of design and evaluation methods R&D, improvement of design and safety analysis capabilities, and development of evaluation methodologies.

4.1 Coordination of Design and Evaluation Methods R&D

Activities under this task include oversight and coordination of efforts to advance design and evaluation methods, interactions with system development teams to coordinate the implementation of system design and safety analysis capabilities, and oversight of the working groups formed to advance methodologies for evaluating Generation IV systems against Generation IV technology goals.

FY 2004 Scope: Provide coordination across Generation IV systems of efforts to advance design and safety analysis efforts. Provide oversight of the development of system evaluation methodologies. Interface with other national programs (e.g., AFCI, NERI) and international activities directed to assessment, improvement and testing of design and evaluation methodologies.

4.2 Assessment and Improvement of Design and Safety Analysis Capabilities

Activities under this task include formulation of requirements on design and analysis capabilities, assessment of existing capabilities and needs for their improvement, initial implementation of required improvements, and identification and compilation of benchmark data applicable to testing of existing and future analysis capabilities.

FY 2004 Scope: An assessment will be carried out to identify key phenomena and system performance figures of merit in steady-state, transient operation, and accident situations. This will support the specification of models that must be represented in neutronic, thermal-hydraulic and safety analysis capabilities. Interfaces will be established with US and international efforts to identify, assess, and document benchmark tests applicable to the qualification of Generation IV system design and analysis physics tools. Capabilities of currently available physics analysis tools will be assessed, and required enhancements to the lattice physics and whole-core modeling capabilities will be identified and their implementation initiated. Finally a review will be conducted of existing thermal-hydraulic design and safety analysis capabilities to identify modeling needs. A review of the status of the experimental database available to for model development, verification and validation will also be conducted and will include scoping type evaluations. Finally, additional needs to provide benchmark confirmation of thermal-hydraulic and safety analysis capabilities will be identified.

Because development of the NGNP (VHTR) has highest priority in the US Gen IV program, the principal focus of the foregoing activities will be to advance tools for design, safety confirmation and licensing of the NGNP. Relevant issues in the areas of reactor physics include the double heterogeneity of coated particle fuel, neutron streaming in the gas-coolant channels, and neutron spectrum transition at the core/reflector interface. For thermal-hydraulic and system analysis tools, relevant phenomena (for both the VHTR and the GFR) include coolant hot streaking and mixing, natural convection and thermal stratification, and dynamic/control implications of

coupling the reactor heat source with thermo-chemical hydrogen generation (water splitting) processes.

4.3 Development and Application of Evaluation Methodologies

Activities under this task are directed to advancing methodologies for evaluating system performance against Generation IV goals. Methodology working groups for Economics Modeling and PR&PP initiated their work in FY 2003. Development efforts of these groups will be continued in FY 2004, and test applications to Generation IV systems will be initiated.

4.3.1 Economics Modeling Working Group

FY2004 Scope: The capital and production cost sub-models will be implemented in developmental software, and verification testing of the software will be performed. Databases of labor and commodity prices will be compiled for applications of the methodology to economic evaluations for different world regions. Draft specifications will be developed for the integrated economic model. Requirements will also be formulated for the economic sub-model on hydrogen and other non-electricity energy products, as well of the optimal plant scale sub-model.

4.3.2 PR&PP Expert Group

FY 2004 Scope: Methods appropriate for evaluating the PR&PP measures for the different threat categories (defined in FY 2003) will be identified and documented. The methods will be tested and further refined through application to an example assessment case. Systematic approaches for characterizing uncertainties in the evaluation of measures and metrics will be investigated.

Table 1. Budget for FY 2004 Design and Evaluation Methods Tasks ($K)

Task	ANL	INEEL	ORNL	BNL	Univ./ Industry	Total
Coordination of Design and Evaluation Methods R&D						
Enhancement of Design and Safety Analysis Capabilities						
Economics Model Development						
PR&PP Methodology Development						
Total						

4.4 FY 2004 Milestones

- Issue draft of PR&PP proposed assessment methodology, 6/30/04
- Report on specifications for an integrated nuclear economic model, 7/31/04
- Report on assessment and initial improvements of reactor physics tools for NGNP analysis, 9/30/04
- Issue status report on T-H/safety modeling capability and data needs for gas cooled reactors, 9/30/04

5 DESCRIPTION OF FY 2005 SCOPE

The work scope is described in this section is based on the Administration's FY 2005 budget request, i.e., the "target" funding level.

5.1 Coordination of Design and Evaluation Methods R&D

Activities under this task include interactions with system design and methods development teams to define and implement a coordinated plan of R&D to advance Generation IV design and safety analysis methods. They also include oversight of the GIF working groups formed to advance methodologies for evaluating Generation IV systems against Generation IV technology goals.

FY 2005 Scope: Provide coordination and direction of efforts to assess, improve, and test Generation IV design and safety confirmation tools. Interface with and exploit related efforts in the US and other countries. Provide oversight and coordination for efforts to develop and test system evaluation methodologies. Work to ensure timely completion of each group's planned activities.

5.2 Assessment and Improvement of Design and Safety Analysis Capabilities

Activities under this task include further specification of Generation IV system design analysis needs, review of existing capabilities, and adaptation of these capabilities to address the identified needs.

FY2005 Scope: Computational modeling requirements will be further defined and implemented to support Generation IV system design and safety evaluations. The models will represent neutronic, thermal-hydraulic and structural phenomena in Generation IV systems. Extensions of analysis tools (reactor physics, T-H, safety) initiated in FY04 will be continued. The emphasis will continue to be placed on improving tools required for NGNP design development, safety confirmation, and licensing. Benchmark tests will be defined to test adequacy of existing and developmental analysis tools. Specifications and measured results for these benchmarks will be documented to support Generation IV system design and licensing.

5.3 Development and Application of Evaluation Methodologies

Activities under this task are directed to advancing methodologies for evaluating system performance against Generation IV goals.

5.3.1 Economics Modeling Working Group

FY 2005 Scope: Sub-models of the integrated economic model for evaluating economics of hydrogen production and of small modular vs. monolithic systems will be developed. These sub-models will be implemented in developmental software and tested through application to selected Gen IV systems.

5.3.2 PR&PP Expert Group

FY 2005 Scope: Methods for evaluating the PR&PP measures will be completed and implemented in analysis tools. Software testing will be performed to verify application to Gen IV systems with open and closed fuel cycles. These methods will accommodate the different threat categories defined through the group's earlier efforts. Approaches for characterizing uncertainties in the evaluation of metrics will be developed. Verification testing and applications to Generation IV systems will be continued.

6 TEN-YEAR PLAN

The high-level ten-year objectives of the Generation IV design and evaluation methods R&D activities are to:

- Enable cost-effective development of high-performance Generation IV systems through coordination and oversight of design related R&D.
- Provide crosscutting capabilities for system design development, safety enhancement, and performance optimization.
- Provide methodologies for measuring the performance of Generation IV systems against Generation IV technology goals.
- Support R&D prioritization based on results of system design analyses and performance evaluations.
- Form the groundwork for licensing the chosen high-performance Generation IV systems via the regulatory process in place when the system development is completed.

The major milestones are as follows:

FY 2005

- Identify and report on required integral experiments to meet nuclear data and neutronic analysis validation needs
- Document benchmark tests to support verification and validation of system dynamics and CFD analysis tools

- Develop energy products model for economic evaluation methodology
- Document PR&PP methods and verify their applicability to Generation IV nuclear energy systems

FY 2006

- Issue draft plan for verification and validation of design and safety analysis software
- Provide assessment report and best-practice guidelines for CFD code application to Generation IV systems
- Report on enhanced Monte Carlo and deterministic capabilities for neutronic and fuel depletion analyses
- Release PR&PP evaluation methodology
- Document implementation and testing status of integrated economic evaluation model

FY 2007

- Report on physics and fuel cycle modeling capability under equilibrium and non-equilibrium conditions
- Report on enhanced system dynamic modeling capabilities
- Issue integrated economic evaluation model

FY 2008

- Update verification and validation plan for design and safety analysis capabilities
- Implement software configuration control for analysis capabilities
- Report on nuclear data assessments and status of validation tests using integral experiments
- Apply economics methodology to evaluations of Generation IV systems (joint responsibility with system development teams)
- Apply PR&PP methodology to evaluations of Generation IV systems (joint responsibility with system development teams)

FY 2009-2010

- Perform verification and validation tests for neutronic design and fuel cycle modeling tools
- Perform verification and validation tests for system dynamics modeling tools
- Implement and qualify revisions of evaluation methodologies

FY 2011 and beyond

- Update design analysis software to accommodate system design changes and address findings of V&V tests
- Report on software verification and validation tests
- Document evaluation methodologies and results of their application testing

The major tasks are supported by funding as shown below in Table 2.

Table 2. Summary of Design and Evaluation Methods Funding Requirements through FY 2013 ($K)

Task	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12	FY13
Coordination of Design and Evaluation R&D										
Development of Crosscutting Design and Safety Analysis Capabilities										
Development and Application of Evaluation Methodologies										
TOTAL										